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**Goldstein, Benjamin Paul; Birkved, Morten; Hauschild, Michael Zwicky; Fernandez, John**

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# Urban agricultural typologies and the need to quantify their potential to reduce a city's environmental 'foodprint'

**Speakers:**
Goldstein, Benjamin[1]; Birkved, Morten[2]; Hauschild, Michael[3]; Fernandez, John[4.]

[1] Technical University of Denmark, Kongens Lyngby, Denmark
[2] Technical University of Denmark, Kongens Lyngby, Denmark
[3] Technical University of Denmark, Kongens Lyngby, Denmark
[4] Massachusetts Institute of Technology, Cambridge, United States

***Abstract:*** *Presently, the supply chain supporting urban food consumption is placing stress on the environment at the planetary, regional and local scales. Despite the urban origin of global food demands, cities supply little of their own food, and are susceptible to disruptions across the global supply chain. One possible mitigation strategy to these issues is increasing food production in and around cities using urban agriculture (UA).*

*Through a literature review, we found claims surrounding UA as a way to attenuate a cornucopia of environmental burdens due to urban food needs, but that their veracity remains inconclusive. A comprehensive analysis of the environmental performance of dominant UA forms is therefore needed. However, the review also found paucity in meaningful systematics that described UA systemsbased on attributes important to environmental performance. We addressed this by developing a system that categorizes UA into five broad types that are optimized for comparing environmental performance.*

*urban agriculture, urban metablism, foodprint, life-cycle assessment, urban resilience*

## Introduction

Global urban population is growing along with development and wealth of many cities and the citizens therein. Cities now contain more than 50% of humanity, and this percentage is only expected to increase into the foreseeable future [1]. Urbanization is also typically linked with increased wealth and resource consumption [2], making the environmental pressures produced by cities discordant with the populations they support [3].

The food consumed by cities has been identified as one of the key consumption categories in terms of influence on urban environmental performance, with the environmental pressures related to urban food *demands* labeled *'foodprints'* [4]. The urban metabolism approach to urban systems analysis has presented itself as an ideal lense with which to assess foodprints, since it endeavours to quantify the sum material and energy demands of a city, typically including food [3]. In recent years, efforts to link urban metabolism with environmental footprinting techniques, such as ecological footprint (EF), carbon footprint (CF) and life-cycle assessment (LCA) have highlighted the importance of the urban foodprint in the discussion of sustainable urban development.

A recent CF of eight US cities identified the urban foodprint as the third largest contributor overall to the cities' impacts at an average of 13% [5], while a study of urban household consumption in Beijing identified food demands as the single largest CF driver [6]. EF assessments are copacetic with these findings, often identifying the foodprint as the largest contributor to a city's EF, e.g. for London [7], Vancouver [8] and Sao Paulo [9]. LCA foodprints have also shown that urban food demands are pivotal in a city's environmental performance [3]. The importance of the foodprint in overall urban sustainability can be traced to the types of foods that urban dwellers consume (meat and dairy), the supply chains that support cities (e.g. 'food miles') and the mismanagement of food related waste in cities [3].

The urban foodprint represents an important area to improve urban environmental performance. This can be done on the demand side by changing the types of foods consumed by urban dwellers through incentivizing low impact diet choices [10] or minimzing food waste or on the supply side through improving the ecological efficiency of the food system supporting urbanites. UA (loosely defined as 'food production in and around cities') falls in to the latter category, and it is increasingly seen as a potential tool to be leveraged by cities to reduce their foodprints and strengthen local food supplies (e.g. New York City [11]).

Literature abounds with a veritable buffet of claims regarding the positive environmental implications of UA to climate impacts, urban nutrient recycling, noise pollution, stormwater flows, biodiversity, and others [12]. However, many of these claims are not fully supported, leaving numerous questions about UA's foodprint reductions potential [13,14]. Moreover, UA exists in a variety of forms (in cities, on buildings, at the edge of cities) yet there is a lack of systematics differentiating between these forms in terms of their environmental performance.

This study addresses these data gaps by performing a literature review to assemble the enviornmental claims regarding UA and assess the extent to which these claims can be justified. We will then begin to outline a typological framework for UA systems that lends itself to application in the realm of quantitative sustainability assessment (QSA), such as LCA, CF, EF and material flow analysis (MFA).

Method

A literature review was performed by accessing scientific and public electronic databases in order to identify literature relevant to UA's sustainability and existing schemes to classify UA varieties. The review was indiscriminate in document type, and therefore, peer-reviewed papers, conference proceedings, books, project reports, governmental reports, theses and magazine articles were assessed, though the focus was on peer-reviewed material.

From December 2013 to January 2014 a series of 13 UA relevant keyterms (e.g. 'urban greenhouse', 'urban foodscapes', 'urban agricultural life cycle assessment', 'urban agriculture typologies', etc.) were used to mine 15 databases (e.g. ISI Web of Science, Google Scholar, Oxford Journals, science.gov, Technical University of Denmark's library, etc.)

Relevant documents were then dissected to determine, (i) what sustainability claims are being made in connection to UA, (ii) support of these claims through field demonstrations and/or models, and (iii) existing UA typological frameworks. Once the absence of a UA systematics relevant for assessing UA environmental performance was identified, we developed a system to fulfill this role using literature on the QSA of both UA and general agriculture (e.g. LCA, CF, EF, industrial ecology), as well as the opinions of experienced experts in the fields of architecture, food LCA and urban sustainability.

Findings

The search yielded a total of 114 documents for perusal. The search mirrored other UA studies in finding that there was a large number of studies espousing the positive environmental impacts of UA [13,14]. Claims concerned impacts from the local scale (heat island attenuation, dust suppression, local air quality improvement) to the global (global warming mitigation, non-renewable resource conservation). Table 1 outlines these claims found in the UA literature reviewed. It also provides a breakdown of the presented quantitative support for these claims. It should be noted that quantitative support was considered as either fieldexperiments or predictions from rigorous models, but not rough estimates.

*Table 1. Summary of environmental claims and supporting literature found in the review. Not an exhaustive list of all of the reviewed material, but a summary of relevant findings. Bold references indicate UA field tests.*

| Sustainability Claim | Quantitative Support |
|---|---|
| Reduction of CF | |
| -food miles [12,15] | -Local production around Osaka, JP could reduce embedded energy in vegetables by 77% [30] |
| -carbon sequestration [16] | -CF reduction modeled for UA in the UK, benefits quickly neutralized by UA growing infrastructure [23] |
| -other | -Packaging savings potentially reduce CF with rooftop UA in Barcelona, ES [24] |
| Increased Eco-Efficiency | |
| -water conservation [17,18] | -Osmosis filtration and rainwater capture satisfied water needs of greenhouse barge off Manhattan, US **[25]** |
| -nutrient recycling [19] | -Wastewater recycling performed in African UA **[26]**<br>-Historical wastewater recycling in Paris, FR contributed significantly to UA [27] |
| Improved Biodiversity [12,16] | -None encountered |
| Reduced Urban Heat Island [13] | -Satellite models showed appreciable heat island effect reduction in NYC, US with hypothetical UA scenario [22] |
| Local Air Quality Upgrading [20] | -None encountered |
| Soil Erosion Prevention [21] | -None encountered |
| Reduction of EF [19] | -None encountered |
| Building Energy Reduction [22] | -Simple model showed 41% heating energy reduction with rooftop UA in northern climate [28]<br>-Modeled energy reduction of 23% for cooling and 20% of building integrated UA in Toronto, CA **[29]** |
| Stormwater Attenuation [22] | -Slowed runoff rate and reduced total runoff from building integrated UA in Toronto, CA **[29]** |

Many of the claims made by UA advocates are supported to varying degrees by quantitative assessments of some kind, and therefore move beyond pure conjecture. However, a number of shortcomings make it difficult to extrapolate the supporting literature's findings to support broader statements regarding the ability of UA to reduce urban foodprints.

1. Where quantitative analsysis is present to support a claim, it has only assessed a single type of UA, thus making it uncertain as to how different UA forms might comparatively perform on the same environmental indicator;
2. Results limited to context of specific urban setting were assessment performed;
3. Some claims had a complete lack of studies to support them, with conclusions made a priori. For instance the assumption of reducing soil erosion is based on UA freeing up agricultural land outside of the city and allowing it to return to its natural state, a scenario that is all but guaranteed in the globally trading agricultural system which will have an increasing population to feed;
4. Assessments focused on one area of envirommental impacts, and therefore, tradeoffs in performance between metrics were ignored (except for [24]). Particularly a near ubiquitous focus on reducing transport distances of food ('food miles') ignores the fact that transport is *very often* of minimal contribution to a food supply-chains overall environmental impacts [31].

Conclusions surrounding the environmental benefits of UA remain murky at best, and assessments are required to determine; (i) how different UA systems compare environmentally, and (ii) what are the tradeoffs between different types of environmental impacts when switching from conventional food supply chains to UA.

To address these data gaps, the predominant UA types have to be elucidated and an assessment methodology applied to them. Clarifying the UA types was found to be difficult after a thorough review of the UA literature had been performed. This was a result of the propensity for socio-economic attributes (e.g. household income, gender of UA practitioner, etc.) and crude topological criteria (e.g. size, location in urban region) to be used in defining existing UA typologies (see [32] for example). Though these UA traits are no doubt essential to judging other aspects of sustainability, they are not functional towards evaluating environmental performance.

Environmentally Relevant UA Typological Framework

In reviewing current UA literature we found large variation in the UA systems utilized (e.g. rooftop greenhouses, vacant lots, etc.). The main goal of the environmentally relevant UA typological framework communicated here is to aggregate similar systems based on the likeness of their material and energy usage patterns, since these factors are related strongly to the ecological burdens of a system [33]. Moreover, the ease of different UA types to affect these patterns through integration with residual urban material and energy flows was considered as *Industrial Symbiosis Potential.*

Using this rationale, five unique and dominant UA types were identified; (i) ground-based, non-conditioned (GB-NC), (ii) ground-based, conditioned (GB-C), (iii) building-integrated, non-conditioned (BI-NC), (iv) building-integrated, conditioned (BI-C), and (v) living-machine (LM). Conditioned refers to a space separated from outdoor elements with controlled settings (temperature, humidity, etc.).Table 2 outlines the material and energy needs of the systems, and provides examples of UA methods that fit within the developed systematics.

*Table 2. Attributes and examples of environmentally relevant UA types. 'high, medium and low' refer to potential differences between UA types, all other variables the same (crop, location, packaging, transport, etc.)*

| | GB-NC | GB-C | BI-NC | BI-C | LM |
|---|---|---|---|---|---|
| **Substrate** | **soil** | **soil or hydroponic** | **soil** | **soil or hydroponic** | **soil, water or hydroponic** |
| **Nutrient Supply** | **artificial, imported, high losses** | **artificial, imported, low losses** | **imported or self-supplied, high losses** | **imported or self-supplied, low losses** | **self-supplied, unknown losses** |
| **Pest Control** | **high** | **low** | **high** | **low** | **low or high** |
| **Irrigation Needs** | **climate dependent** | **low (w/ recycling)** | **climate dependent** | **low (w/ recycling)** | **none** |
| **Energy Supply** | **passive solar** | **solar or grid based** | **passive solar** | **solar, grid based or building supplied** | **solar or grid based** |
| **Infrastructure Inputs** | **low** | **high** | **low** | **high** | **very high** |
| **Industrial Symbiosis Potential** | **low** | **low** | **medium** | **high** | **high** |
| **Cultivation Period** | **seasonal** | **year-round** | **seasonal** | **year-round** | **year-round** |
| **Examples** | **vacant lots, community gardens, allotments, peri-UA** | **greenhouses (peri or central)** | **rooftop gardens, green walls** | **rooftop greenhouses** | **vertical farming, aquaculture** |

The material and energy needs of the UA systems vary widely. Of particular note are the conditioned systems which may have an advantage by virtue of internal recycling mechanisms to capture nutrients and water, while at the same time protecting crops from pests and weather damage [18]. At the same time, conditioned systems require much higher material inputs in the form of permanent infrastructure (greenhouse structure, circulation systems, etc.), with their own embedded environmental burdens from manufacturing. Moreover, building-integrated UA forms distinguish themselves from the ground-based counterparts through the degree of 'industrial symbiosis' they can achieve with the urban environment, either through direct water or nutrient capture, or by influencing the energy use of the buildings with which they are fused [25]. Lastly, the 'living machine' types are intended to adhere to ecological principles of circular energy and material flows, and are envisioned to have very low external demands for these [18], however, the embedded environmental impacts of the associated built infrastructure could be significant.

## Conclusions

Literature shows that UA does hold potential to reduce the foodprints of urban dwellers in some instances, but the conclusions are opaque. Foodprint reduction potentials from conventional urban food supply chains could be significantly different between UA forms for the same product. Moreover, it remains to be seen if a given UA form can reduce the environmental burdens of urban food demands for a given agricultural product, as the potential may exist to exasperate burdens if UA is used out of context (e.g. growing greenhouse tomatoes during the winter as opposed to importing them from a temperate climate). The UA typological framework developed provides a foundation to begin answering these questions using QSA methods and provide information to actors regarding the foodprint reduction potential of UA. Lastly, assessing the city-wide foodprint mitigation of intensive, city-wide UA proliferation will require a combination of these methods with urban metabolism to gauge if UA can make meaningful contributions to overall urban sustainability and urban food system resilience.

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